THE HOLOGRAPHIC GRATING OF THE LYMAN BETA EXPERIMENT OF THE D2A POLAR SATELLITE

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16. Abstract

Several solutions are proposed for luminous small-field spectrophotometry at 1025Å. The use of a specially designed holographic grating permits adapting it to an imposed geometry. The results obtained are reported.

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THE HOLOGRAPHIC GRATING OF THE LYMAN BETA EXPERIMENT OF THE D2A POLAR SATELLITE

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I. INTRODUCTION /155*

The experiment is designed to study the distribution of atomic hydrogen in the atmosphere. Sunlight excites the hydrogen, producing diffusion of the solar Lyman Alpha photons (1216 Å), whereas the geocoronal H Alpha line (6563 Å) is produced by the de-excitation of hydrogen atoms that have absorbed the solar Lyman Beta photons (1025 Å).

It is therefore very interesting to combine with the experiments, which study /156
the H Alpha and Lyman Alpha lines on the D2A Polar satellite, an experiment which

*Numbers in the margin indicate pagination in the foreign text.

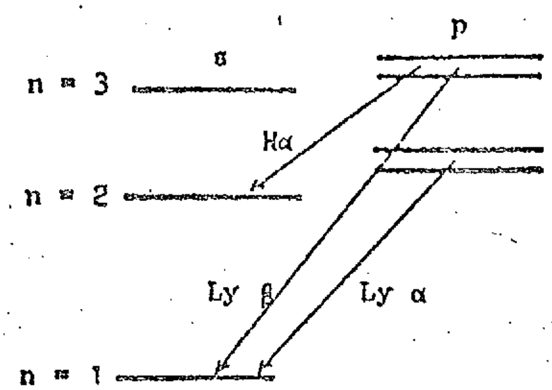

Fig. 1. Transitions between hydrogen atom energy levels.

simultaneously monitors the Lyman Alpha and Lyman Beta lines in the direction opposite to the sun.

The measurement of the Lyman Beta radiation (about 1000 times weaker than the Lyman Alpha radiation) requires a spectrometer with a high softening power for Lyman Beta. This is the primary requirement.

On the other hand, its field should be small and less than 15° in order to observe sufficiently fine detail and to be able to produce partial maps of the geocorona at each instant of time.

II. ENGINEER'S CONSTRAINTS

The dispersing assembly had to be placed in an already existing structure in the form of a cylinder 20 cm in diameter and 20 cm high, closed at its ends by two plates on which the optics had to be mounted. A 20-cm long baffle could be attached to the outside of the bottom plate. The detector system could be mounted on the outside of the upper plate. The ray path is folded in the form of a Z.

The design, fabrication and tests of the spectrometer had to be accomplished in less that one year. /157

The team at Verrieres-le-Buisson in charge of the development of this experiment included:

M. Fournet - Responsible for D2A scientific equipment.

A. Soufflot - Coordination.

S. Vidal - Electronics, mechanical.

J. Desalos - Optics.

J. Porteneuve - Development of computer programs.

M. Olivie - Assistance in the spectrometer design.

M. Dennefeld - Scientific responsibility for the experiment.

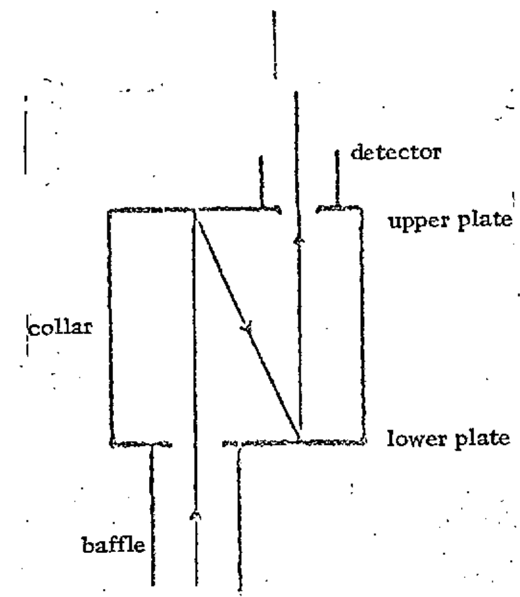

Fig. 2. Mechanical assembly.

III. SPECTROMETER DESIGN

A) Basic Specifications of the Spectrometer

1. Luminosity-resolution trade-off. The response function is the convolution of the source function by the instrument spread function. The latter has a trapezoidal form for a slit spectrometer (on the diagram below the entrance slit 1 is assumed to be larger than the exit slit 1').

The light-gathering power of the instrument (equal to the ratio of the recorded radiation to the luminance of the source entrance slit) is proportional to the height of the instrument spread function and therefore to the width of the smaller slit.

The instrument resolution (equal to the ratio of the average observation wavelength to the smallest resolved spectral interval) is inversely proportional to the width of the instrument spread function and therefore to the width of the larger slit.

The light-gathering power-resolution trade-off therefore means taking the minimum resolution (that is, ability to distinguish the Lyman Alpha and Lyman Beta lines) and finding 1' = 1 which yields the maximum light-gathering power. The profile of the instrument spread function is then triangular.

The physical obstructions are smallest at the focal plane, and therefore the size of the exit slit is held at its maximum (13 × 13 mm). The entrance slit, fixed at the end /158

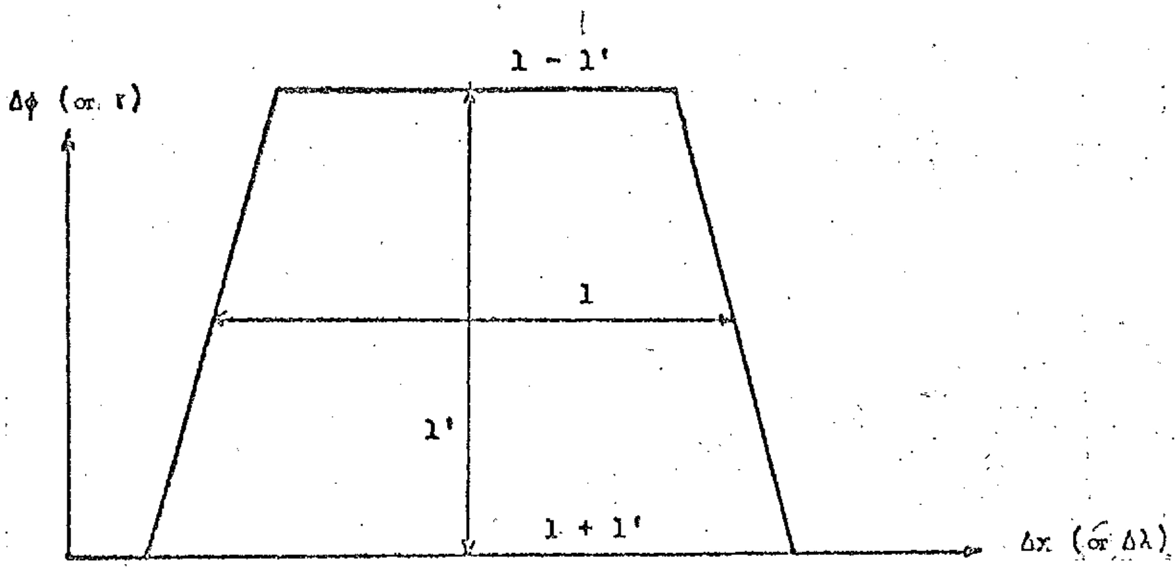

Fig. 3. Instrument spread function.

of the baffle, is its conjugate (15 × 15 mm).

In order to obtain the maximum light-gathering power, given the possible obstructions, the grating must have ϕ = 50 mm. The stigmatic solutions require a nearly normal incidence on the grating. The dispersion law tells us then that nK ~ 4000 (the product of the number of lines/mm and the diffraction order).

2. Small field. The spectrometer employs only reflective surfaces, the number of which should be as small as possible (the best surfaces reflect 65 % in Lyman Beta). One is led to use a concave grating.

The field θ is proportional to ϕ /D (the size ϕ of the aperture divided by the pupil-aperture distance D) and it is of interest to increase D in order to reduce the field since it is impossible to reduce the grating and diaphragm size without losing light-gathering power.

B) Possible Solutions

Given the previously-fixed Z-shaped mechanical configuration, there are two satisfactory solutions.

1. Collimator baffle solution. A baffle-collimator has been studied *** stack of 37 identical, randomly-spaced gratings. The system is rather complex since it /159

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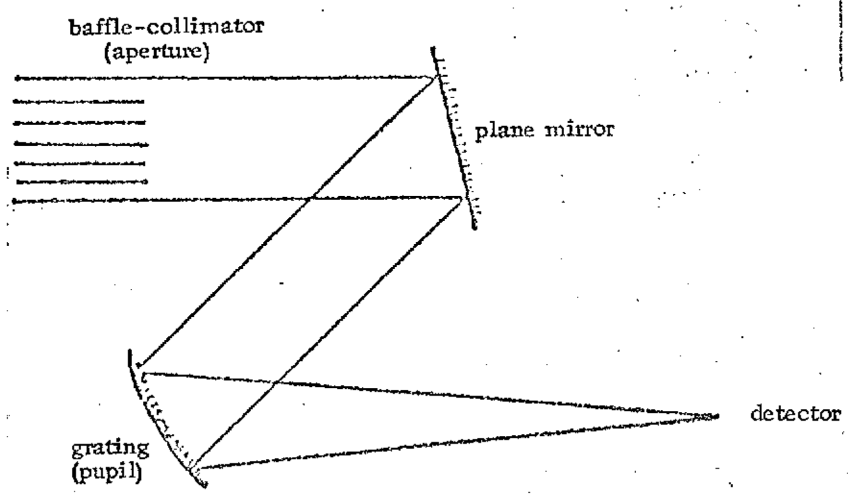

Fig. 4. Spectrometer with baffle-collimator.

would have to be built with a high precision, from light material, antireflection coated, and would have to withstand space, thermal and vibration qualification tests. All of this would be impossible within the time available.

2. Entrance-slit solution. For a grating with ϕ = 50 mm and D = 250 mm, the pupil-aperture distance allowed by the mounting, the average field is 11°, which is acceptable.

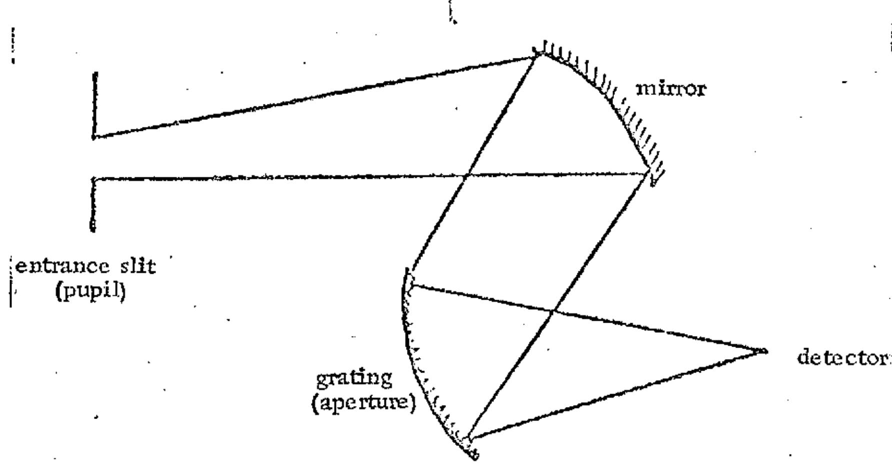

Fig. 5. Slit spectrometer.

IV. GRATING DEFINITION

A) Concave Ruled Gratings

These can be made with a high precision on metal substrates, but the blaze angle (which determines the efficiency) is more difficult to control. If they are used on a Rowland circle, a point source image becomes a straight line of height $h = 2\phi \sin i \tan i$, a function of the grating size ϕ and the incidence angle i.

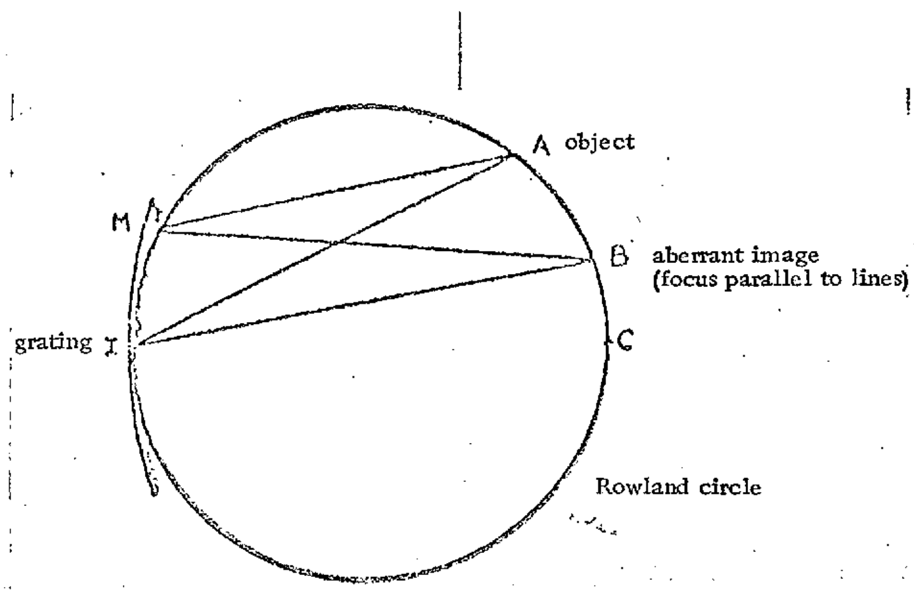

Fig. 6.

For example in our case, $i = 30°$ and $\phi = 50$ mm, h = 29 mm.

Such an astigmatic focus cannot be tolerated since it involves a considerable loss of flux and too much stray light due to the enlargement of the image. /160

The holographic gratings make it possible to obtain fringes of any form whatever, so that stigmatism is attainable.

B) Holographic Gratings

1. Generalities. On a surface ε of arbitrary form, one records the intersection of the interference volume, corresponding to two coherent point sources C and D, with the surface ε. The fringes reproducing the equal-phase lines are recorded on a photosensitive layer on ε. A chemical treatment causes a relief to appear, analogous to rulings and resembling fringes. This surface is metallized in vacuum and the deposit can be treated with far UV.

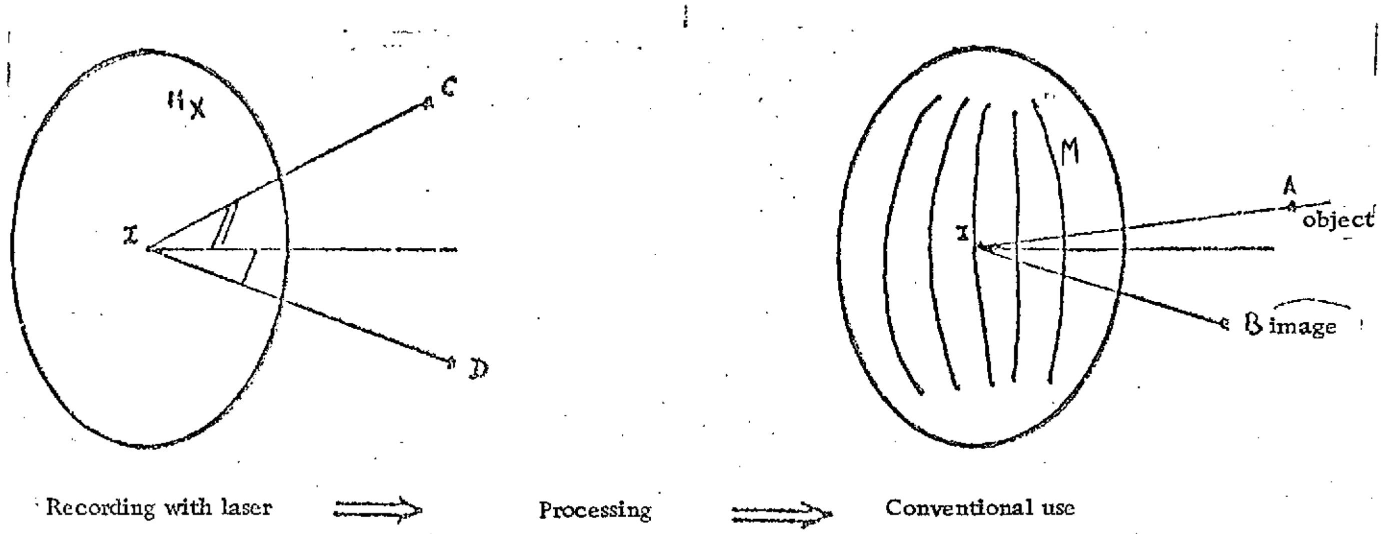

Fig. 7.

The grating is then used in the conventional manner. In use, two particular points A and B, characteristic of the grating, correspond to the recorded points C and D.

The advent of the holographic gratings may be very important; they have no ghosts and little stray light.

2. Stigmatism conditions. In order to have stigmatism between A and B, the optical path L = (MA) + (MB) must be constant, $\forall$M.

$$\Delta(M) = \big((MA) + (MB)\big) - \big((IA) + (IB)\big) \quad \text{modulus} \quad \rho$$ /161

If one sets $(IA) + (IB) - k\,\frac{\lambda}{\lambda_o}\big((IC) - (ID)\big) = \tau$, the stigmatism condition $\Delta = 0$ becomes:

$$(MA) + (MB) - k\,\frac{\lambda}{\lambda_o}\big((MC) - (MD)\big) = \tau = \text{constant} \quad \forall M$$

This is the relation between the recording points C, D and the two particular stigmatic points A, B used.

For a concave grating one finds the recording configurations that give rigorous stigmatism at certain points. For example, for a recording point C at the center and any second recording point D, stigmatism is obtained, at a given wavelength, between the point A at the center and the point B harmonically conjugate to D with respect to the ratio of the circle tangent to the grating (sic ?). This is the type 3 grating in the Jobin-Yvon catalog.

3. Study of third-order aberrations for a spherical grating. One can also attempt to minimize the aberration error Δ in the third order; M. Flamand has developed the geometrical calculations.

The point M of the grating is specified in XYZ Cartesian coordinates; the points A, B, C, D of the XY plane in polar coordinates with respect to the vertex I of the grating must be α, β, γ, δ, l_A, l_B, l_C, l_D.

One sets $A = 1/l_A$, $B = 1/l_B$, $C = 1/l_C$, $D = 1/l_D$, ρ is the curvature $\rho = 1/R$, λ_0 is the wavelength of the recording laser, λ is the operating wavelength, K is the diffraction order. /162

$$A = -Y\left(\sin\alpha + \sin\beta - K\frac{\lambda}{\lambda_0}(\sin\delta - \sin\gamma)\right)$$

dispersion term

$$+\frac{Y^2}{2}\left(A\cos^2\alpha - \rho\cos\alpha + B\cos^2\beta - \rho\cos\beta - K\frac{\lambda}{\lambda}(C\cos^2\gamma - \rho\cos\gamma) + K\frac{\lambda}{\lambda_0}(D\cos^2\delta - \rho\cos\delta)\right)$$

tangential astigmatism term

$$+\frac{Z^2}{2}\left(A - \rho\cos\alpha + B - \rho\cos\beta - K\frac{\lambda}{\lambda_0}(C - \rho\cos\gamma - D + \rho\cos\delta)\right)$$

sagittal astigmatism term

$$+\frac{Y^3}{2}\Big(A\sin\alpha(A\cos^2\alpha - \rho\cos\alpha) + B\sin\beta(B\cos^2\beta - \rho\cos\beta) - K\frac{\lambda}{\lambda_0}\big(C\sin\gamma(C\cos^2\gamma - \rho\cos\gamma) - D\sin\delta(D\cos^2\delta - \rho\cos\delta)\big)\Big)$$

1st coma term

$$+\frac{YZ^2}{2}\Big(A\sin\alpha(A - \rho\cos\alpha) + B\sin\beta(B - \rho\cos\beta) - K\frac{\lambda}{\lambda_0}\big(C\sin\gamma(C - \rho\cos\gamma) - D\sin\delta(D - \rho\cos\delta)\big)\Big)$$

2nd coma term

+ higher order aberration terms.

V. THE TWO HOLOGRAPHIC GRATING SOLUTIONS

A) "Type 3" Solution

This mounting uses the type 3 stigmatic grating.

The grating has 1680 lines/mm (recording is over 54°), R = 192 mm. Illuminated 30° at 240 mm, it diffracts Lyman Beta along the normal in the 3rd order at the distance of 192 mm. The dispersion between Lyman Beta and Lyman Alpha is 6°30' and the tangential focus in Lyman Alpha is 2 mm.

This solution uses a well-known type of holographic grating, which is stigmatic for the Lyman Beta and nearly stigmatic for Lyman Alpha. The entrance mirror is flat. /163

But then one obtains a superposition of the first-order 3075 line with the 3rd order Lyman Beta. The experimentally measured efficiency is less than 3%.

One is therefore forced to calculate a formula for a pseudo-stigmatic holographic grating.

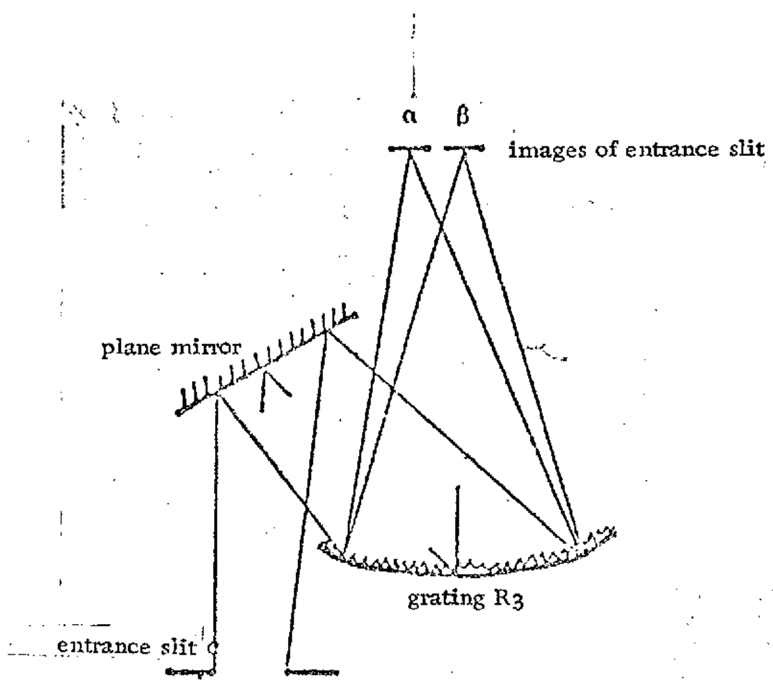

Fig. 8. Type 3 solution.

B) "Type 4" solution

The condition $\Delta = 0$ must be verified for every point of the grating.

The imposed conditions are: $\lambda_0 = 4880$ Å, $\lambda = 1025$ Å, $\alpha - \beta = 30°$, K = -1.

$K = \pm 1$ seem to be the more efficient orders; we have taken the Wadsworth assembly as an example and chosen $K = -1$.

One fixes $\delta = -\gamma = 50°$ (therefore $n = 3140$ lines/mm),

Formula I provides us a system of 5 equations:

The solution of the first dispersion equation gives $\alpha = -5.4°$, $\beta = 24.6°$.

There remain 4 equations with 4 unknowns and one parameter $\rho = 1/R$.

The system has two roots and we retain the solution:

$$l_A = 0.543\ R, \quad l_B' = 7.73\ R, \quad l_C = 36.3\ R, \quad l_D = 2.92\ R.$$

The distance $l_A = 221.7$ between the grating and the exit windows, imposed by the mechanical design of the experiment, gives us R = 408 mm.

(ILLEGIBLE LINE)

In order to verify the weak effect of the residual aberrations, one traces *** the light rays. The method used is based *** the operator corresponding to a classical grating, but one must assign to every point of the grating a vector in the plane tangent to the grating, giving the direction of the fringes and their separation (the vector is determined by the recording configuration). /164

The blur spots on the shutter plane have been determined at each λ for one hundred rays. We found the aberrations to be small.

Instead of the square theoretical images, 12.8 mm on a side one obtains:

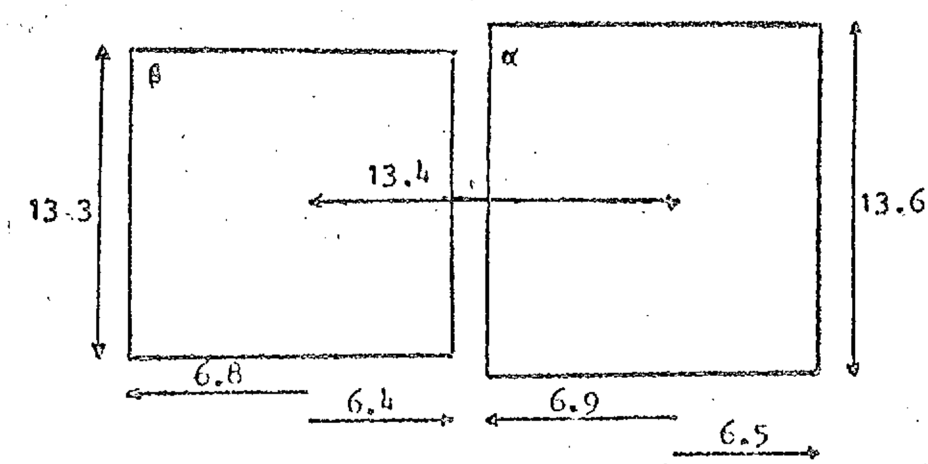

Fig. 9. Actual images.

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This program has also been used to determine the fabrication tolerances; it is found that 5% on the length of the recording arms and 1° on the angle between these two arms are sufficient to preserve stigmatism.

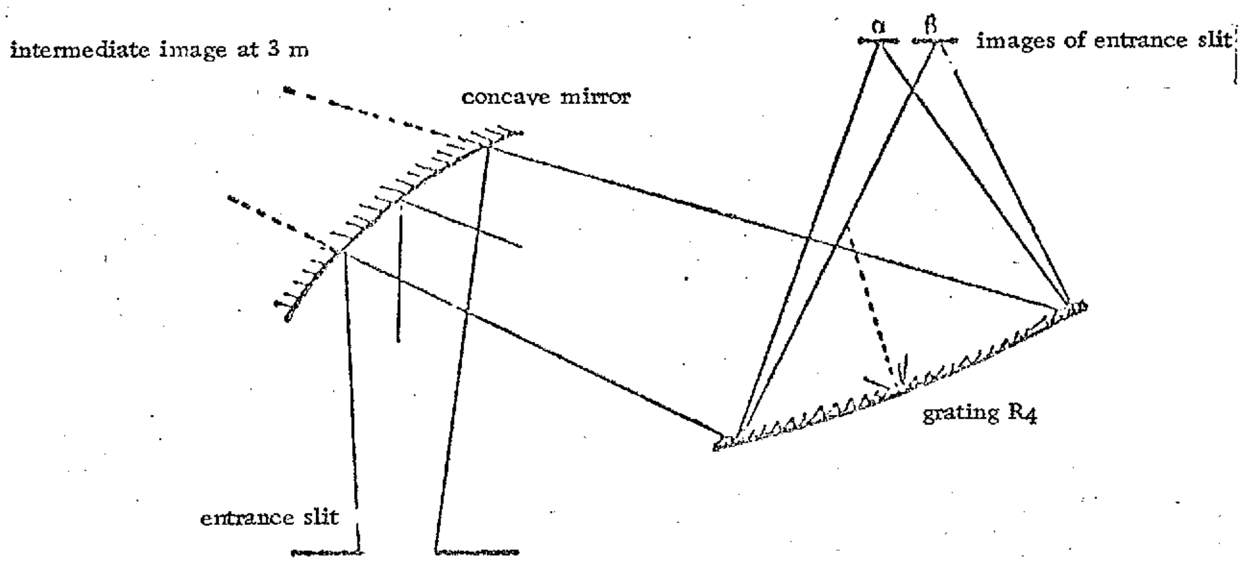

Fig. 10. Type 4 solution.

A concave collector mirror must be combined with the grating in this assembly. It operates off-axis and must be hyperbolic in order to be stigmatic. We have not been able to make this off-axis mirror and have used a spherical collector whose inherent aberrations (of the order of a mm) must be added to those of the grating.

Here one sees the *** of the holographic gratings; *** aberrations of the prior system by imparting the inverse residual aberrations to the grating, and that just by changing the recording points. This fascinating idea will permit using only spherical surfaces in the open and folded assemblies. /165

C) Fabrication

The Jouan-Quetin - Jobin-Yvon Company handled this. Silica substrates have been used. An angle greater than 50° between the recording arms cannot be obtained

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easily. The accuracy of the length of the arms is obtained quite easily. The asymmetry between the length of the arms (15 m versus 1.5 m) has necessitated resorting to several special tricks during assembly.

The most difficult parameter to control is the efficiency (stability of the argon-ion laser, determination of the exposure and development times), which is related to the geometry of the grooves. A series of measurements has allowed us to select the best gratings.

The REOSC Company has made the magnesium drums with a system of three nylon clamps that squeeze the edge of the grating. This permits the thermal expansion to be compensated and provides a rigid system in the presence of vibration without noticeably affecting the state of the surface.

The far UV coating was deposited by the SEAVOM Company using Al-LiF-MgF_2; the MgF_2 layer serves to protect the LiF.

VI. EXPERIMENTAL STUDY

Since the holographic gratings have not been previously used in space, an experimental study of their characteristics was undertaken.

A) Preliminary Studies

At CNES, M. Lamenardie has performed the preliminary studies for the purpose of testing the holographic gratings and the surface treatment. These involved thermal and aging tests.

This work is now being continued.

B) Efficiency Tests /166

1) First we checked the spectral reflection of the Al-LiF-MgF_2 coating alone; the measurements made at SEAVOM have been verified at the Max Planck Institute of Munich, Garching (with a plasma arc and a converter). This coating has a reflectivity of more than 50% between 1020Å and 1300 Å, and is of the order of 60% at 1025 Å and 55% at 1216 Å.

2) The efficiency tests made at SEAVOM were with a windowless H_2 lamp and differential pumping.

One can define two efficiencies at each λ:

The intrinsic or absolute efficiency E_i = the ratio of the radiation diffracted in the given order to the radiation reflected by a mirror coated in the same manner.

The real efficiency F_r = the ratio of the diffracted radiation to the incident radiation.

$$F_r = \tau . E_i$$

"Type 3" concave gratings, 1600 lines/mm.

We have made assemblies that permit testing at 1216 Å in the same configuration that is to be used in space.

The efficiency varied by a factor of less than 2 between the third order and the neighboring orders.

The efficiency varied by a factor of 3 with the recording technique (the 4 gratings studied were not identical).

The intrinsic efficiency was below 3.5%.

"Type 4" concave gratings, 3200 lines/mm.

The efficiency again varied by a factor of 2 with the recording technique (test gratings).

The intrinsic efficiency reached 20%, which gives a real efficiency of 15%.

Flat gratings, 3600 lines/mm.

The efficiency varied symmetrically around the 1st order, and in the 3rd order it dropped by a factor of 3 with respect to the 1st order.

The intrinsic efficiency reached 30%.

Flight-model concave gratings, 3140 lines/mm.

A spectral study has been performed on four gratings, the recording scheme being identical in all cases. Three gratings gave very similar results, with the measurement accuracy being about 10%. /167

The intrinsic efficiency decreased with wavelength, with the real efficiency remaining practically constant:

λ Å	1254	1216	1163	1124	1066	1025 extrapolated
F_i	27	26	24	22	21	20
F_r	14	14	13	13	13	13

In view of these results we have selected the "type 4" spectrometer design.

C) Stigmatism Tests:

An attempt was made to check whether the grating stigmatism is less than a mm.

The type 3 gratings, operating in the 3rd order at 1025 Å, were tested in the normal fashion at Jobin-Yvon by examining an Airy spot at 3660 Å in the first order.

The type 4 gratings have been tested in an assembly that simulates our flight configuration. The test object was a wide slit (2/10 to 2 mm).

The image space was scanned with a narrow slit at the theoretical focal distance. We found that the response profile at 1216 Å was the predicted trapezoidal function.

VII. LYMAN BETA EXPERIMENT

A) Spectrometer Characteristics (see Fig. 11)

A 15 × 15 mm entrance slit at the end of the baffle.

Concave spherical collector, ϕ = 50 mm, R = 573 mm, tilted 15°.

Concave holographic grating, ϕ = 50 mm, R = 408 mm, 3140 lines/mm, illuminated over 24.6°.

Shutter system with two assymetrical baffled slits and a mechanism for dividing the response into 3 bands: Lyman Beta, Lyman Alpha, and no radiation.

Two methods of internal calibration, allowing control of aging.

On-board logic (internal program or by telemetry command) controls the mechanisms.

Detector: we have abandoned use of a fluorescent converter or channeltron in favor of an electron multiplier. This detector permits use of an interchangeable window. Its first dynode of CuBeO has a quantum yield of 10% at 1025 Å. Its supply voltage is 3750 V. It is connected to a counter and the amplification circuitry has a gain of 1200.

The shaped pulses are sent to a floating-point counter and the data are sent by /168
telemetry to the ground station.

B) First Calibration Results

The calibration of the overall experiment was done at Verrieres-le-Buisson and at Munich.

The Lyman Alpha band is centered at 1220 Å and it has a spectral width of about 100 Å, it counts 6 pulses/4 seconds for 10^6 Lyman Alpha photons/sec/cm^2.

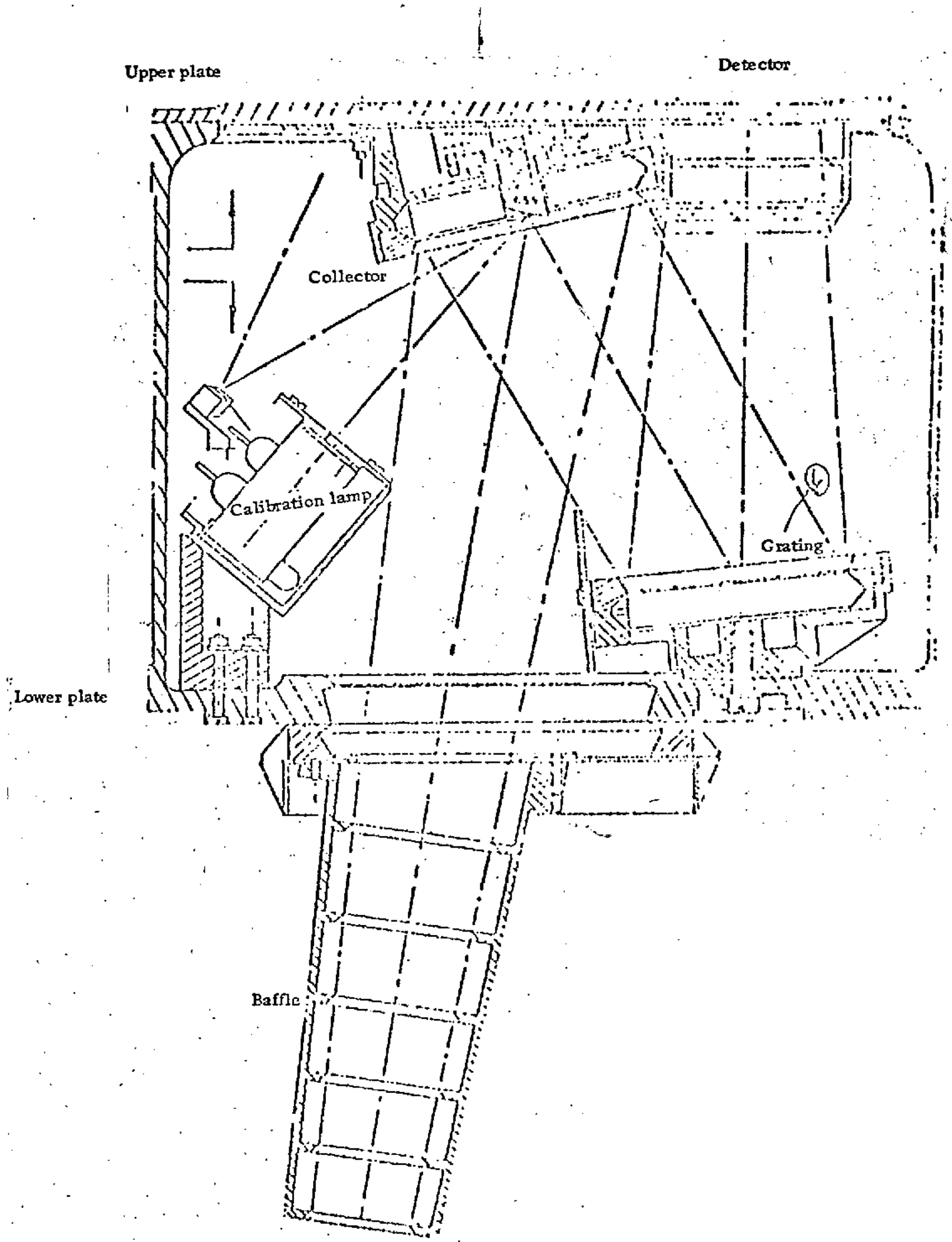

Fig. 11. Mechanical assembly.

The Lyman Beta band has a sideband centered at about 1220 Å, it *** 5 times better 1120 Å than 1220 Å; 500 times more Lyman Beta than Lyman Alpha must be counted.

The analysis of the results is now in progress.

VIII. CONCLUSION

Our data underscore the value of holographic gratings for obtaining rather uncommon spectrophotometer configurations. It is a space "first" since the experiment should be in orbit before the end of 1971. This example of use in the fat ultraviolet, with its mechanical constraints, the necessity of satisfying the standards on space materials and the reduction in implementation delays should result in an extension of the use of holographic gratings in spectroscopy.

REFERENCES /170

1. Dennefeld, M., J. Desalos, A. Soufflot and S. Vidal. The Lyman Beta experiment on the D2A Polar satellite, Internal Report of the Service d'Aeronomie du CNRS, March 1971.
2. Bousquet, F. Spectroscopie instrumentale (Instrumental Spectroscopy), Dunod.
3. Beutler, H.G. Theory of concave grating, J. Opt. Soc. Am., 35, No. 5.
4. Olivie, M. Detection of the Lyman Beta and Lyman Alpha emission of the geocoronal hydrogen, Study Report - Ecole Polytechnique Laboratoire d'Optique et de Physique Moleculaire, March 1971.
5. Cordelle, J., J. Flamand, G. Pieuchard and A. Labeyrie, Proceedings of VIII-th ICO Congress, Reading, July 1969.
6. Cordelle, J., J. Flamand, G. Pieuchard and A. Labeyrie. Proceedings of 2 Days of Optics at CNES, September 1969.
7. Labeyrie, A. and J. Flamand. Optics Commun., 1, April 1969.
8. Petit, R. Rev. Opt., June 1966, August 1966.
9. Cordelle, J., J. P. Laude, R. Petit and G. Pieuchard. Rev. Opt., 1, No. 3, Jan. 1970.
10. Pavageau, J. Rev. Opt. May 1965, September 1965, November 1965, January 1966.
11. Pavageau, J. C.R. Acad. Sciences Paris, 258 , Group 5, March 16, 1964.

***Translator's note: The original text is illegible.

12. Flamand, J. Private communication, September 1970.
13. Marechal, A. Geometric Images and Aberrations (Ed. of the Revue d'optique).

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